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## Assessment of the Suitability of Baghouse Dusts from a Dust Extractor as Fillers for Hot-Mix Asphalt

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### Abstract

The paper presents the study results of the structural features and functional properties of the limestone filler as well as the basalt and amphibolite dusts from a dust extractor of a Hot-Mix Asphalt plant in Poland. Additionally, the selected physical and mechanical properties of asphalt concrete 0–16 mm in laboratory conditions were evaluated.

The principal purpose of the study is to understand the structural and functional properties of baghouse dusts and “fillers mixed” from the perspective of their use as fillers for Hot-Mix Asphalt (HMA).

The analysis of the results of grain-size distribution, specific surface, air voids of dry compacted fillers, increase in the softening point using the Ring & Ball method, as well as selected properties of the AC 16, all have shown that the studied baghouse dusts meet the requirements of fillers for HMA. Research results have also shown that these dusts as “fillers mixed” with limestone filler optimally meet the requirements of fillers for HMA.

Presented results contribute substantially to expanding the knowledge in the field of the quality, structure and functional properties of fillers.

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### 1. Introduction

Mineral fillers used in Hot Mix Asphalt (HMA) can be considered as [1]:

- basis filler (limestone dust produced by industrial method),
- mineral fines founded in aggregate after passing through a hot air stream in dryer mixer,
- baghouse fines from a dust extractor installed in an asphalt mixing plant.

The first two types of fillers are almost always a major component of HMA, used in the construction of asphalt pavement layers. The usability of the third type of filler is restricted by rules [2].

The Polish standard PN-S-96025:2000 allows the use of baghouse fines instead of a quantity of basis filler in asphalt pavement layers provided that these baghouse fines receive a favorable decision from a road laboratory or Technical Approval [3]. Since the European standard PN-EN 13043:2004 became valid in law some of its sentences concerning dusts and fillers are contradictory to requirements of the PN-S-96025:2000 standard.

In many countries, baghouse fillers are admitted as suitable to use in HMA as a mineral fillers [1], [4]. In France and USA, the fines from a dust extractor installed in an asphalt plant are the basic source of mineral filler which are utilized in HMA as a whole. In Belgium, both baghouse and limestone fillers were used, and the application of baghouse fillers is not

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limited if results of laboratory tests are positive. However, in England limestone filler was added to HMA as a supplement of filling fraction of an aggregate in quantities resulting from required grading of mixture [1].

The application of mineral dusts from a dust extractor installed in an asphalt plant as a filler for Hot-Mix Asphalt (HMA) has recently been the focus of interest of the Polish Roads Building Companies. In 1997, the first Polish paper was published on the use of baghouse fines in HMA mixtures. Grzybowski [1] reported on the application of baghouse fillers in HMA paving mixtures mainly on the basis of American technical literature [5], [6], as well as on his own experiences gained during his involvement in international road construction contracts. He drew up guidelines for ensuring an effective use of baghouse fines in HMA paving mixtures.

The common use of dusts from a dust extractor from current production in central asphalt mixing plants carries high reprocessing costs, and the need for special transport. Depending on the awareness of the decision-making body, there are two approaches to implementing dusts from a dust extractor:

- leaving a portion of the limestone filler (usually 2%) and completing the rest of the dusts from a dust extractor – this partly satisfies the financial concerns, and additionally lowers the risk of using the dusts from a dust extractor, which are mostly a part of various types of aggregate.
- the assumption of using dusts in entirety – an economy-oriented approach without a margin for the quality of the obtained dusts.

Using dusts is largely an economic issue, with quality and ecology taking lower priority. It is essential, however, to realize that the use of dusts from a dust extractor has a considerable impact on the quality of the asphalt mixture. Although the values of all the required parameters in laboratory conditions are positive, it is not necessarily reflected in the execution of a contract. One should particularly bear in mind the compaction of such an asphalt mixture and the process of laying, during which an individual approach must be applied, with a close observation of the mixture for any cracks, displacements, or bulges in front of a compaction roller. It is connected with the type of dusts from a dust extractor, the share of particular aggregates we obtain dusts from, and the amount of dusts used. Meeting the stringent requirements in the technological regime, the asphalt mixture is a product of the same quality as the lime-dust mixture. The use of dusts in the production process requires that the operating software has the option of separate dosage of dusts tank to filler weight. The control of such dosage is important to meet specific objectives. It is a key issue in light of maintaining the production consistency in reference to the effective system of plant quality control.

The focus of studies realized at the Poznan University of Technology [7], [8] was on mineral fillers obtained from a dust extractor of an asphalt plant in Poland. The tested materials included grano-dioryte, basalt, dolomite and melaphyre dusts. Limestone was used as the reference filler in the research program. Quantitative estimation of grain morphology of baghouse dusts was performed, which fundamentally extended the knowledge concerning the influence of structure and grain morphology of mineral dust on its functional properties.

Zulkati, A. *et al.* [9] carried out research of the influence of filler on the qualities of mastics. They examined three fillers, i.e. granite dust, slaked lime and kaolin. When preparing samples of mastics they noticed that the specific surface of filler has a marked influence on the amount of bitumen used (the smallest amount of bitumen was used in the production of mastics with the use of granite dust). The type of filler influences the workability and compaction. Wang H. *et al.* [10] proved that the stiffening effect of mastics is greatly influenced by filler porosity (according to Rigden's concept) and filler granulation.

This paper expands the research scope with the study of the impact of the type of mineral filler on the basic physical and mechanical properties of High Modulus Asphalt Concrete 0–16 mm (HMAC 16).

## 2. Objective and scope of the study

The paper presents the results of the analysis of structural characteristics and functional properties of mineral dusts from a dust extractor in the production of hot-mix asphalt (baghouse dusts).

The object of research and analysis were 6 samples of mineral dusts of various origins, with the following symbols: B (basalt dust), A (amphibolite dust), 3B1L (filler fixed 75% of basalt dust and 25% lime filler), BL (mix of 50% of basalt dust and 50% lime filler), 3A1L (mix of 75% of amphibolite dust and 25% lime filler) and AL (mix of 50% of amphibolite dust and 50% lime filler). For comparative analysis, an extra sample of limestone filler was prepared (L).

The chief purpose of the study is the assessment of the suitability of baghouse dusts from a dust extractor as fillers for Hot-Mix Asphalt. The main evaluation criteria are Technical Requirements No. 1 [11] and No. 2 [12].

The research program had two stages:

1) The analysis of structural and functional attributes of mineral dusts, such as:

- Grading of filler aggregates (air jet sieving) acc. to EN 933-10.
- Specific surface acc. to EN 196-6 (acc. to Blaine).

- Air voids content acc. to EN 1097-4 (acc. to Rigden).
- Methylene Blue Value acc. to EN 933-9.
- Increase in the Softening Point of mastics acc. to EN 13179-1.
- The volume of “solid phase” in mastics [13].

2) The analysis of selected physical and mechanical properties of HMAC specimens.

The second stage involved designing the composition of asphalt mineral mixture (grading 0–16 mm) with the use of analyzed mineral dusts, fillers fixed (mixtures of dust and limestone) and lime filler, intended for wearing course made of High Modulus Asphalt Concrete (HMAC) for the traffic category KR-5 and KR-6 (i.e. when annual daily traffic in equivalent 10-ton axle pressure per line is  $> 1,000$ ). The composition of analyzed HMAC 16 mixtures is presented in Table 1. The composition of the mineral mixtures for HMAC 16 is designed to grading curves for all samples were the same.

Table 1. Composition of analyzed mixtures HMAC 16

Type of material, d/D	Composition, %			
Filler	L, B, fillers mixed	6,7	L, A, fillers mixed	5,7
Crushed sand 0/2	basalt	28,5	amphibolite	22,9
Chippings 2/5		14,3		15,2
Chippings 5/8		13,3		15,2
Chippings 8/11		13,3		15,2
Chippings 11/16		19,0		21,0
Bitumen 20/30		5,0		4,7
Adhesive agent Wetfix BE (in relation to bitumen)		0,3		0,3

The following physical and mechanical properties of the asphalt concrete samples were calculated:

- Air voids content acc. to EN 12697-8,
- Volume density acc. to EN 12697-6,
- Water sensitivity acc. to EN 12697-12,
- Permanent deformation resistance acc. to EN 12697-22,
- Stiffness acc. to EN 12697-26,
- Stability and settlement acc. to EN 12697-34.

### 3. The study of structural features and functional properties of fillers

The study results of grading (air jet sieving) acc. to EN 933-10 is presented in Fig. 1. The grading of all analyzed samples complies with Technical Requirements No. 1 [11] for fillers in layers of asphalt concrete, i.e. passing sieve # 2 mm is 100%, passing sieve # 0,125 mm is  $> 85\%$ , and passing sieve # 0,063 mm is  $> 70\%$ .

The measurement results of specific surface acc. to Blaine's method, presented in Fig. 2, indicate that lime filler L ( $SS = 5,332 \text{ cm}^2/\text{g}$ ) has definitely the biggest specific surface, whereas amphibolite dust A ( $SS = 2,501 \text{ cm}^2/\text{g}$ ) the smallest. The addition of lime filler L to mineral dusts increases parameter  $SS$  in dust-lime mixes (fillers mixed). With the exception of lime filler L, the analyzed materials comply with the Polish norm PN-S-96504 (measured values  $SS$  are within 2,500–4,500  $\text{cm}^2/\text{g}$ ). The specific surface of the fillers was calculated as the arithmetic average of the eight measurements.

The Rigden voids (porosity) was calculated using Rigden's method acc. to EN 1097-4, and the results are presented in Fig. 3. The porosity of the fillers was calculated as the arithmetic average of the six measurements. All analyzed samples comply with Technical Requirements No. 1 [11] (required  $RV = 28\text{--}45\%$ ). The highest void volume was noted in amphibolite dust A ( $RV = 38,7\%$ ). The lowest void volume was noted in lime filler L ( $RV = 34,4\%$ ).

The result analysis reveals a close correlation between the specific grain surface and porosity  $RV$  of analyzed samples (the increase in value  $SS$  leads to the decrease in Rigden voids  $RV$ ). Consequently, the addition of filler L to dusts causes the decrease in the value of parameter  $RV$  in dust-lime mixtures.

The results of methylene blue value  $MB_f$  are shown in Fig. 4. The  $MB_f$  value was calculated as the arithmetic average of the six measurements. All analyzed samples comply with Technical Requirements no. 1 [11] (required  $MB_f \leq 10 \text{ g/kg}$ ), which confirms that they contain small quantities of dust-clay fraction.

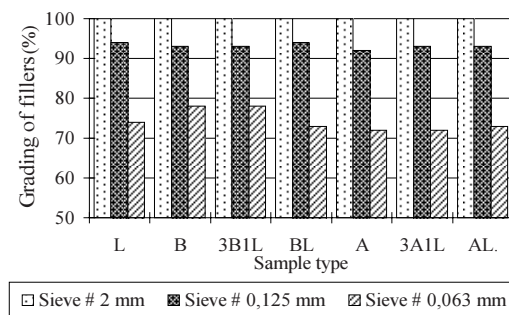


Fig. 1. The grading of fillers (air jet sieving)

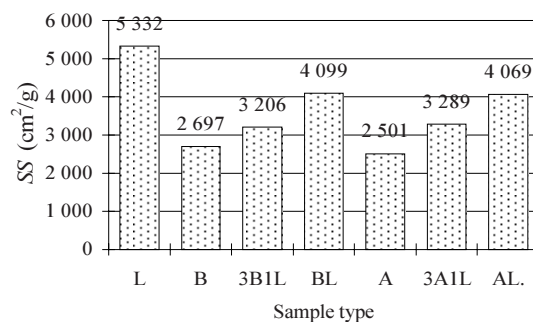


Fig. 2. The specific surface of samples acc. to Blaine's methods (SS)

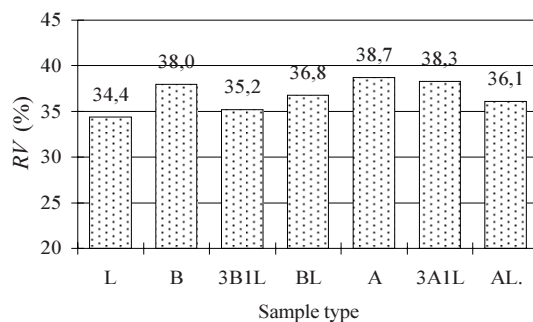
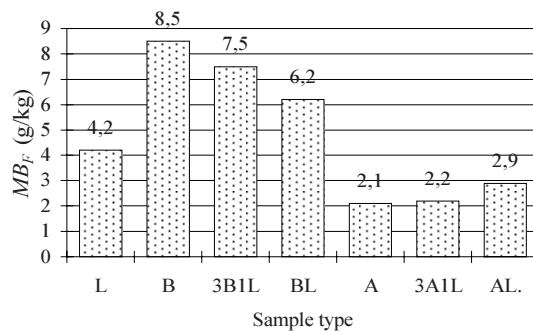


Fig. 3. The Rigden voids of samples (+)

Fig. 4. The methylene blue value of samples ( $MB_F$ )

The study of fillers' stiffening quality was conducted on samples of bituminous mastics with mineral dusts, fillers mixed and lime filler (vol. ratio F/B = 0.60). The value of mastics stiffness was based on the increase in softening point ( $\Delta T_{R\&B}$ ) in comparison with the softening point of road bitumen 70/100 ( $T_{R\&B}$ ), measured in accordance with the EN 13179-1 standard.

The increase in softening point is presented in Fig. 5. These results were calculated as the arithmetic average of the six measurements. All analyzed samples (except filler L) comply with Technical Requirements No. 1 [11], because the increase in the softening point for bituminous mastics is within the range  $\Delta T_{R\&B} = 8\text{--}25\text{ }^{\circ}\text{C}$ .

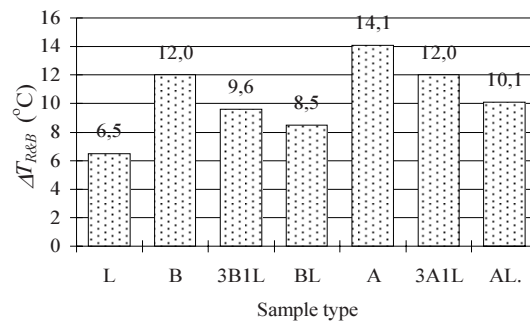


Fig. 5. Increase in Softening Point of samples ( $\Delta T_{R\&B}$ )

However, according to Francken and Moraux [14], the recommended increase  $\Delta T_{R\&B}$  should be  $12.6\text{ }^{\circ}\text{C}$ . A bigger increase in this quantity may indicate that the mineral filler used in the mastics has excessive bitumen absorptivity. According to this criterion, the dust that shows such excessive absorptivity, and a large stiffening effect in mastics, is the amphibole dust (A) as  $\Delta T_{R\&B} = 14.1\text{ }^{\circ}\text{C}$ .

In the case of dust-lime mixtures, it was observed that the lime filler (L) has a significant influence on decreasing the stiffening of fines-asphalt mastic.

The results presented in Fig. 5 indicate that, in comparison with lime filler (L), mineral dusts have a significantly bigger stiffening effect in mastics. It results from high voids content  $RV$  in samples B and A whose values are presented in Fig. 3.

#### 4. Structural features of fillers vs. the structure of filler-bitumen system

Properties of bituminous mastics (including their stiffness) depend significantly on the conditions of the interaction between the surface of dust grains and the bituminous binder, which are a function of physical adsorption, numerous sorption processes and capillary filtration of bitumen to the surface of grains. Thin films of “fixed asphalt” formed around the mineral grains, as shown in numerous studies [13, 15], are characterized by specific modified properties, different from those in the mass of the “free asphalt”.

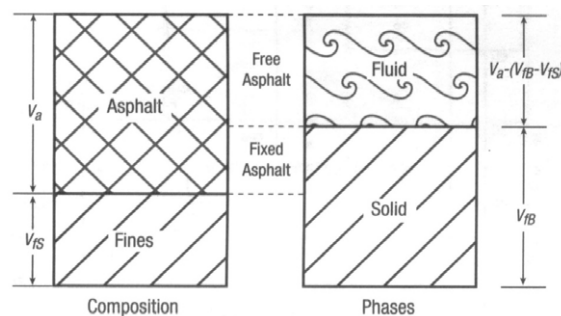


Fig. 6. Fraction voids in filler-bitumen systems ([13];  $V_a$  = volume of bitumen binder,  $V_{FS}$  = volume of filler (solid particles),  $V_{FB}$  = bulk volume of compacted filler,  $V_{af}$  = volume of free bitumen)

The interpretation of this phenomenon is closely connected to the phases concept in fines – asphalt systems (Fig. 6), presented by Rigden. In mastic, a specified part of the bituminous binder, which fills the pores of the filler, is “fixed” with a

filler and increases the volume of the solid phase [16]. The remaining binder, i.e. the excess, is treated as “free asphalt”, which imparts a liquid nature of the mixture (hence the name “liquid phase”).

The bulk volume of the compacted fillers in the mastics, i.e. the volume of “solid phase”, may differ due to the nature of the fines (e.g. the shape and particle size, the grain-size distribution and the grain surface texture) and a higher bulk volume would result in more “fixed asphalt” and less “free asphalt”, thereby causing more stiffening of fines-asphalt mastic [13, 15, 17]. Values of the percentage volume of “solid phase” ( $V_{fb}$ ) should be equal to or less than 60%. When  $V_{fb} > 60\%$ , fillers cause excessive stiffening effect in HMA mixtures which may be less resistant to tensile forces.

Fig. 7 shows a bulk volume of compacted fillers ( $V_{fb}$ ) in the mastics according to Rigden’s concept for proportion of F/B = 0.60 by volume. The highest bulk volume of “solid phase” was noted for amphibolite dusts A ( $V_{fb} = 61.2\%$ ), and the lowest for the mixture 3B1L ( $V_{fb} = 57.9\%$ ). It may indicate that dust A used in mastics has excessive bitumen absorptivity, as  $V_{fb} > 60\%$ . This is a confirmation of the study results of softening point temperature, in which the increase of  $\Delta T_{R\&B}$  for dust A is bigger than that recommended by Francken and Moraux [14], ( $\Delta T_{R\&B} = 14.1\text{ }^{\circ}\text{C} > 12.6\text{ }^{\circ}\text{C}$ ).

It was observed that the specific surface of the filler influences the percentage volume of “solid phase” in the mastic. The smaller the specific surface of filler grain, the bigger the volume of “solid phase” in the bituminous mastic. It was also observed that the volume of “solid phase”  $V_{fb}$  has a significant impact on the increase in the softening point in bituminous mastics  $\Delta T_{R\&B}$ . The higher the percentage volume of “solid phase” in the mastic, the bigger the  $T_{R\&B}$  increase of mastics, and thus stronger stiffening effects of fillers.

Both domestic and international literature lacks detailed information on the correlation between structural properties of fillers and the thickness of film of “fixed asphalt”. Also, there is no data on the significance of the influence of the thickness of film of “fixed asphalt” on the functional properties of mastics or hot-mix asphalt.

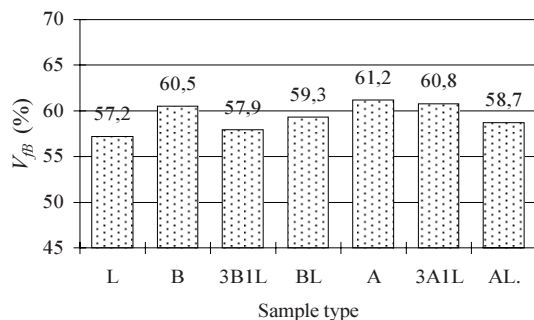


Fig. 7. Bulk volume of compacted fillers ( $V_{fb}$ ) in the mastics

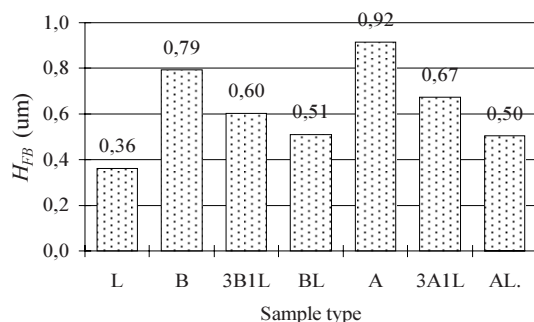


Fig. 8. The thickness of film of “fixed asphalt” ( $H_{fb}$ )

In this paper, the thickness of film of “fixed asphalt” was determined applying the Rigden’s concept, and using the results of measuring the Rigden voids ( $RV$ ) of mineral fillers mentioned above. This is based on the theory that the bituminous binder, which fills the pores of the filler, is “fixed” with a filler and increases the thickness of film of “fixed asphalt”.

Fig. 8 shows the study results of the thickness of film of “fixed asphalt”. It was confirmed that filler porosity has a considerable influence on the thickness of film of “fixed asphalt”. The greater the porosity of samples, the thicker the film of “fixed asphalt” in mastics.

The analysis of the qualities of mineral dusts, limestone filler, and dust – lime mixtures confirmed the theses proposed by the authors in their previous studies [15–17] on the significance of influence of certain structural parameters on fillers' functional properties (stiffening) regardless of the type and origin of the samples. The vital parameters are: specific surface  $SS$  and porosity  $RV$ , which have a considerable impact on shaping the filler-bitumen structure, and thus on the functional properties of bituminous mastics.

Research results show that studied baghouse dusts meet the requirements of fillers for HMA, but these dusts as “fillers mixed” with limestone filler meet the requirements optimally.

## 5. Physical and mechanical properties of asphalt concrete samples (HMAC 16)

The study results of physical and mechanical properties of asphalt concrete HMAC 16 are shown in Tables 2 and 3. These results were calculated as the arithmetic average of the two measurements.

The purpose of this research was to confirm the validity of the positive assessment of the usability of mineral dusts (baghouse dusts) as basis filler and mixed filler with lime filler in HMA, which was shown in 4 (above). The main assessment criteria are Technical Requirements No. 2 [12].

Table 2. The study results of HMAC 16 samples with basalt aggregate

Sample type	L1 <sup>1)</sup>	B	3B1L	BL
Quality	Results			
Voids content, $V$ , %	3.2	3.5	3.8	3.8
Bulk density, $Mg/m^3$	2.631	2.645	2.643	2.635
Water sensitivity <sup>2)</sup> $ITSR$ , %	100.8	94.6	91.6	94.8
Permanent deformation resistance <sup>3)</sup> : $WTS_{AIR}$ , $mm/10^3$ cycles	0.08	0.06	0.04	0.03
$PRD_{AIR}$ , %	5.6	5.1	5.3	4.8
Stiffness <sup>4)</sup> $E$ , MPa	16,704	15,946	15,489	15,364
Stability, $S$ , kN	14.2	12.8	13.5	13.9
Settlement, $F$ , mm	3.6	3.1	3.7	3.4

<sup>1)</sup> Sample L1 – HMAC 16 sample with lime filler and basalt aggregate.

<sup>2)</sup> Stored at 40 °C with one freezing cycle, tested at 25 °C.

<sup>3)</sup> Method B in air, at 60 °C, 10,000 cycles.

<sup>4)</sup> 4PB-BR, at 10 °C, frequency 10 Hz.

Table 3. The study results of HMAC 16 samples with amphibolite aggregate

Sample type	L2 <sup>1)</sup>	A	3A1L	AL
Quality	Results			
Voids content, $V$ , %	3.5	3.8	3.5	3.7
Bulk density, $Mg/m^3$	2.553	2.549	2.551	2.544
Water sensitivity <sup>2)</sup> $ITSR$ , %	84.3	81.3	84.6	82.6
Permanent deformation resistance <sup>3)</sup> : $WTS_{AIR}$ , mm	0.03	0.05	0.04	0.05
$PRD_{AIR}$ , %	3.1	4.0	5.3	4.8
Stiffness <sup>4)</sup> $S$ , MPa	16,269	15,553	15,626	15,396
Stability, $S$ , kN	14.9	12.8	14.1	14.3
Settlement, $F$ , mm	3.4	3.0	3.2	3.4

<sup>1)</sup> Sample L2 – HMAC 16 sample with lime filler and amphibolite aggregate.

<sup>2)</sup> Stored at 40 °C with one freezing cycle, tested at 25 °C.

<sup>3)</sup> Method B in air, at 60 °C, 10,000 cycles.

<sup>4)</sup> 4PB-BR, at 10 °C, frequency 10 Hz.



The study results in Tables 2 and 3 indicate that all analyzed HMAC 16 samples comply with Technical Requirements No. 2 [12] for voids content (required scope  $V = 2\text{--}4\%$ ), water sensitivity (required  $ITSR_{80}$ ), permanent deformation resistance (required  $WTS_{AIR\ 0.15}$ ), and stiffness (required  $S_{14,000}$ ).

It was observed, however, that mineral dusts and dust-lime mixtures have a negative impact on water sensitivity, stiffness and stability of HMAC 16 samples, especially amphibolite dusts.

No direct correlation was found between the structural and functional properties of the mineral fillers and the physical and mechanical properties of HMAC samples. Only the stability  $S$  and settlement  $F$  of asphalt concrete samples show a relationship with such qualities of fillers as specific surface  $SS$ , porosity  $RV$ , bulk density of “solid phase”  $V_{FB}$ , the thickness of the film of “fixed asphalt”  $H_{FB}$ , and the increase in the mastic’s softening point  $\Delta T_{R\&B}$  (stability  $S$  and settlement  $F$  increase with  $SS$  and decrease with  $RV$ ,  $V_{FB}$ ,  $H_{FB}$  and  $\Delta T_{R\&B}$ ).

Based on the analysis of research results, it can be concluded that mineral dusts and the addition of mineral dust in lime filler have a negative impact on the physical and mechanical properties of asphalt concrete HMAC 16 in comparison with “clean” lime filler, commonly used in road construction. But despite the negative influence of dusts and dust-lime mixtures, HMAC 16 samples containing them comply with Technical Requirements No. 2 (2010) and can be deemed useful for HMA.

## 6. Conclusions

The research results and their analysis let us conclude the following:

- all tested samples of mineral dusts and dust-lime mixtures comply with Technical Requirements No. 1 [11] for quality (i.e. harmfulness) of dusts, graining, porosity, and the increase in softening point,
- the increase in softening point, as well as the volume of „solid phase”, indicate that amphibolite dust (sample A) may cause excessive bitumen absorptivity and high stiffness of mastics (vol. ratio F/B = 0.60),
- the addition of lime filler (sample L) to mineral dusts decreases the stiffening effect of the lime-dust mixture in the bituminous mastic,
- mineral dusts and the addition of mineral dust to lime filler, in comparison with “clean” lime filler, have a negative influence on water sensitivity, stiffness and stability of HMAC 16 samples (especially amphibolite dust),
- all analyzed samples of asphalt concrete comply with Technical Requirements No. 2 [12] for voids content, water sensitivity, permanent deformation resistance, and stiffness.

Regardless of the type of mineral filler used, it was observed that:

- the lower the voids content in the filler, the thinner the film of “fixed asphalt” in the mastic,
- the smaller the specific surface of filler grain, the bigger the volume of “solid phase” in the mastic,
- the higher the volume of “solid phase” and the thickness of the film of “fixed asphalt” in the mastic, the bigger the increase in the mastic’s softening point, thus a stronger stiffening effect of the filler,
- the stability and settlement of asphalt concrete increases with the volume of specific surface, and decreases with the Rigid voids of filler, the volume of “solid phase”, the thickness of the film of “fixed asphalt” in mastic, and the increase in the mastic’s softening point.

Therefore, it can be conceded that the analyzed mineral dusts as a basis filler, and the dust-lime mixtures as mixed filler, can be used effectively in HMA.

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